

The Habitat of Winter Ticks (*Dermacentor albipictus*) In The Moose (*Alces alces*)
Range of Northeast Minnesota

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Dedication

This thesis is dedicated to my family who ignited my passion for wildlife, the outdoors, and learning. They have always encouraged, supported, taught, and loved me, and they also taught me the faith I need to accomplish all of my goals.

Abstract

Winter ticks occur throughout moose range south of 60° N, but little is known about how habitat influences tick density in Minnesota. Adult female winter ticks drop off moose in the spring to lay eggs and larvae attach to moose in the fall. The habitat that a tick drops off into could increase or decrease either survival or reproduction. Moose select different cover types for foraging and for bedding. We used locations of moose wearing GPS collars to identify tick sampling locations. Moose GPS locations could be identified as either movement or bedding. Targeted sampling at moose GPS locations allowed us to evaluate flag and walking surveys for winter tick collection. Bed sites and movement paths were identified from the 2013 and 2014 spring tracks to assess the effect of moose behavior and habitat characteristics on tick density. Moose GPS locations had more ticks than random sites ($p = 0.001$). Tick densities at moose sites were higher in 2013 (10.8 ± 2.9 ticks/m²) than in 2014 (2.8 ± 1.2 ticks/m²; $p = 0.0003$). Ticks were found at 52% of 2013 sites and at 27% of 2014 sites. More movement paths than bed sites had ticks in 2013 ($p = 0.01$), but tick densities were similar in bed sites (11.2 ± 6.3 ticks/m²) and movement paths (10.7 ± 7.5 ticks/m²). In both years, tick density was higher in areas with litter depths < 3 cm ($p \leq 0.06$) and with canopy closures < 50% ($p \leq 0.008$). A high percentage of sites in lowland conifer, mixedwood, and regenerating forests had ticks present, but no upland conifer sites had ticks present ($p = 0.0001$).

Spring locations from GPS collared moose were converted to paths. These paths were areas where ticks would have dropped off of moose. We created paths of moose in the fall by connecting GPS locations. Fall paths were overlaid with spring movement

paths to identify areas where moose could acquire ticks. Overlaps of the 2011-2012 spring and fall path accounted for 6 and 13% (3.1 ± 0.4 ha and 2.2 ± 0.5 ha) of the paths. All moose overlapped with their own path in the fall for about 4% of their spring paths (1.1 ha). The greatest areas of overlap occurred in mixedwood and wet cover types ($p = 0.0002$).

Mixedwood and wet cover types, especially with open canopies and shallow litter depths, have the highest potential to produce high larval tick densities. Mixedwood and wet cover types also have the greatest area of overlap between spring and fall paths and could be the areas with the highest tick transfer.

Tick densities estimated from walking surveys and tick densities estimated from flag surveys were similar ($p = 0.9$). Walking surveys with chaps allowed us to identify the height of winter ticks on the vegetation. The largest clumps of ticks were found at 38.2 ± 3.4 cm, but ticks were found from 0-100 cm. When more ticks were collected with walking surveys, ticks were generally found below 66 cm. When more ticks were collected with flag surveys, ticks were found above 66 cm and were likely higher than chap height.

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**Chapter 1: The Effects of Habitat and Host Activity on Larval Winter Tick
(*Dermacentor albipictus*) Densities**

Introduction

The habitat for an ectoparasite is relatively constant while on a host. For the part of their life cycle off of the host, habitat variables such as vegetation, soil, and precipitation become important if they affect parasite survival. In ectoparasites like ticks, different life stages rely on the litter and vegetation for protection during growth and for finding a new host. Some habitats may have conditions which increase parasite survival. Identifying habitat effects on parasite density will increase the understanding of the biology of the parasite-host interaction.

The winter tick (*Dermacentor albipictus*) lives in litter and vegetation for approximately 3 months in summer. The off-host period begins when adult female ticks drop-off of their host (Drew and Samuel 1989). Egg laying begins in late May and early June, and eggs hatch in late August or early September (Drew et al. 1985).

The habitat in which ticks drop off can affect survival and reproduction because engorged female ticks move < 60 cm after dropping off (Drew and Samuel 1986a). Female tick survival is reduced if temperatures are below - 5 °C, if snow is present, or if the female drops off under a closed canopy (Drew and Samuel 1986a).

Female ticks need temperatures of at least 16 °C for egg laying (Aalangdong et al. 2001). Temperatures in habitats with closed canopies were lower than in habitats with open canopies, and survival of female winter ticks was lower in cover types with closed canopies (Drew and Samuel 1986a, Aalangdong 1994, Aalangdong et al. 2001). Female tick survival and larval production was higher in open habitats of upland shrub, grassland, bog, and aspen stands (Drew and Samuel 1986a, Aalangdong 1994,

Aalangdong et al. 2001).

Larval ticks climb nearby vegetation two weeks after hatching and begin questing for a host (Drew and Samuel 1985, Samuel et al. 2000). Ticks begin questing in Ontario in mid-September (Addison et al. 1979). In Alberta, larvae wait on vegetation in aggregations of 10 to 1,000 ticks from September to November (Drew and Samuel 1985, McPherson et al. 2000). Aggregations remain on the vegetation and can survive for 3-4 months until they transfer to a host, blow away, become covered with snow, or die (Drew and Samuel 1985, McPherson et al. 2000). This typically occurs by November. Larval tick activity is reduced below 3 °C with death occurring below -10 °C (Samuel et al. 2000, Samuel 2007).

The normal host of the winter tick is the white-tailed deer (*Odocoileus virginianus*, Samuel 2004). Winter tick range has expanded northward as the deer range has expanded and winter ticks have encountered other hosts (Mooring and Samuel 1998). Other winter tick hosts include cattle (*Bos taurus*), horses (*Equus caballus*), mule deer (*O. hemionus*), elk (*Cervus elaphus*), caribou (*Rangifer tarandus*), and moose (*Alces alces*) (Drummond et al. 1969, Welch et al. 1991, Mooring and Samuel 1998, 1999, Samuel 2004). The winter tick has become an important parasite of moose populations where winter tick and moose ranges overlap (Samuel et al. 2000, Drummond et al. 1969, Samuel 2004). Moose acquire 10,000 to >100,000 ticks in Alberta and New Hampshire (Drew and Samuel 1985a, Mooring and Samuel 1998, Bergeron and Pekins 2014). Large tick loads over 30,000 can lead to hair-loss, secondary bacterial infection, anemia, and death (Drew and Samuel 1989, Samuel 1991, McLaughlin and Addison 1996, Mooring and Samuel 1999,

Musante et al. 2007).

Ticks are commonly sampled by using a cloth drag or flag (Drew and Samuel 1985*a*, Carroll and Schmidtman 1992, Daniels et al. 2000, Castro and Clover 2010, Dantas-Torres et al. 2013, Bergeron and Pekins 2014). Tick drags over long transects have been effective at collecting winter ticks (Drew and Samuel 1985*a*, Aalangdong 1994, Bergeron and Pekins 2014). However, sampling along transects does not allow for targeted sampling of ticks to answer questions about microhabitat characteristics or host behavior (Bergeron and Pekins 2014).

Research on winter tick habitats outside of Alberta is needed, particularly in relation to host behavior. Habitat types across winter tick range need to be sampled for winter ticks to determine what other habitats support the survival and reproduction of winter ticks. We used fine-scale movement data from moose in northeast Minnesota to determine if open habitats in northeast Minnesota have the microhabitat characteristics needed for winter tick survival and reproduction. The fine-scale data also allowed us to identify bed sites and movement paths.

We hypothesized that moose activity during tick drop-off and the habitat that ticks drop into influences tick presence and tick density. The objectives of this study were to: 1. measure winter tick density at bed sites and on movement paths; 2. identify how microhabitat characteristics of litter, duff, soil moisture, ground cover, vegetation height, canopy closure, and cover type affected winter tick density; 3. evaluate weather effects on tick density; and 4. contrast winter tick density at GPS collar locations of moose with winter tick densities at random sites.

Methods

Study Area

This study took place in the same study area as Lenarz et al. (2009) in the arrowhead region of northeast Minnesota (47°30'N, 91°21'W, Fig. 1.1). Much of the study area is part of the Superior National Forest. The study area has a humid continental climate with severe winters and short dry summers. Precipitation occurs in the form of snow (180 cm annually) and rain (70 cm annually), 40% of which occurs during the plant growing season (NOAA 2001-2010). Snow cover is typically present from December through April. The soil is influenced by the Laurentian glacial shield providing poor draining soil that supports sedges (*Carex* spp.), Labrador tea (*Ledum groenlandicum*), black spruce (*Picea mariana*), white cedar (*Thuja occidentalis*) and tamarack (*Larix laricina*). Lakes and wet areas are surrounded by grey alder (*Alnus incana*) and red osier dogwood (*Cornus sericea*) that transitions into upland mixedwood forests (MNDNR 2014). Upland vegetation consists of fire-dependent forests dominated by a mix of eastern white and red pine (*Pinus strobus* and *P. resinosa*), quaking aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*), white spruce (*Picea glauca*), and balsam fir (*Abies balsamea*).

Weather Conditions

The beginning of the snow free period for each year was identified using National Operational Hydrologic Remote Sensing Center Interactive Snow Information Maps (NOAA, Washington, DC, USA). The snow free period began on May 8, 2013 for the 2013 field season. The snow free period began May 5, 2014 for southern locations in the

study area and May 8, 2014 for the northern locations. Daily average temperatures during the tick drop-off season for May 8 – 28, 2013, May 6 - 15 2014, September 15 to November 26, 2013, and September 18 to October 18, 2014 were downloaded from the National Climatic Data Center (NOAA, Washington, DC, USA).

Identification of Bed Sites and Movement Sites

In 2013, we collected moose locations every 20 min on 2 female moose with Lotek Iridium GPS collars (Lotek Wireless, Inc., Newmarket, Ontario Canada). GPS locations from moose collars were visually examined on Google Earth (Google Inc. 2013, Version 7.1.1.1999, Mountain View, California, USA) to identify bed sites and movement paths within 500 m of a road or trail. Bed sites were identified as a clump of 3 or more consecutive within a 5 m radius. We assumed the moose was inactive and resting or ruminating at these clumped locations (Moen et al. 1997). The bed site location we used was determined by taking the average location of the UTM coordinates (Moen et al. 1997). We assumed that moose were either walking or browsing when GPS locations were not clumped at bed sites. Movement paths were identified by 3 or more locations with the most extreme locations separated by more than 10 m, but less than 40 m.

In 2014, the sample size was expanded to 20 female moose with GPS locations collected at 1 hour intervals. Moose were wearing Vectronics Iridium GPS collars (Vectronics Aerospace, Berlin, Germany). Moose locations from May 2014 were visually examined using ArcMap 10.1 (ESRI, Redlands California, USA) to identify bed sites and movement paths within 500 m of a road. Bed sites and movement paths could not be identified from 1 hour locations with as much confidence as when using the 20-

min locations in 2013. Presumed bed sites were identified as a cluster of 2 or more consecutive locations within a 5 m radius. The center of the bed site was determined by taking the average of UTM coordinates (Moen et al. 1997). Presumed movement paths were identified as 3 or more locations with the most extreme locations separated by more than 10 m, but less than 40 m. The beginning of the movement path was identified as the first chronological point.

Moose beds and movement paths were identified during the snow free period of the tick drop-off season, because survival of female ticks that dropped off on snow was only 11% in Alberta (Drew and Samuel 1986a). Sites sampled in fall 2013 were identified from bed sites or movement paths May 8 to May 28, 2013. Sites sampled in fall 2014 were from bed sites or movement paths from May 7 to May 15, 2014.

Locations for random sampling of ticks in different cover types were created with ArcMap 10.1 (ESRI, Redlands, CA, USA) in 2013. Random sampling locations were created by assigning 50 points to each of the Land Use Land Cover (LULC, MNDNR 2014) types within moose home ranges that were within 300 m of roads within the study area. Random sites were sampled in 2 clear cuts, 6 lowland conifer stands, 9 conifer stands, 8 deciduous stands, 5 mixedwood stands, 18 prescribed burns, and 5 regenerating forests.

Tick Sampling

In 2013, 21 bed sites and 27 movement paths from 2 moose were sampled for winter ticks from September 15 to October 20. Random cover types were sampled from September 28 to November 16. In 2014, 100 bed sites and 100 movement paths from 20

moose were sampled from September 18 through October 18.

Sites were sampled with a square 1 m² white flannel flag clipped to a 1.5 m long PVC electrical conduit with paper binders. The free end of the PVC conduit was held with the flag on the right side of the body. Flags were dragged across the vegetation keeping the greatest surface area of the flag in contact with the vegetation (Bergeron and Pekins 2014). The sampling flag was checked for ticks every 1-3 m. When ticks were found on the flag, the species and height of the vegetation sampled just before the presence of ticks on the flag were recorded. The flannel was folded and placed into a Ziploc® bag at the end of the movement path or bed site sampling. If ticks were not found, clinging vegetation was picked off and the flag was re-used.

Sampling at bed sites in 2013 and 2014 started at the center of the bed. Flags were dragged in concentric circles for a diameter of 10 m. The total area sampled at each bed site was 78.5 m². For movement paths, flags were dragged from GPS location to GPS location in chronological order. At the end of the movement path, the flags were dragged in reverse chronological order back to the beginning of the movement path to make a sampling width of 2 m (Drew and Samuel 1985a). Moose did not likely walk a straight line path from point to point, but the exact path was not known. Because of GPS error (Moen et al. 1996, 1997) and the uncertainty of the movement of the moose between locations, the area sampled was not the same path walked by the moose. The sampled area probably reflects a minimum tick density. The sampling area for movement paths was determined by the distance walked times the sampling width and ranged from 79 to 584 m². Tick densities were determined by dividing the total number of ticks found at a

site by the area sampled.

Random sampling was completed with a 50 m transect. Random transects were sampled in random cover types in areas that were not associated with GPS collar locations. Transects were sampled by walking the transect with the flag on the right side of the body. The observer turned around and walked back to the beginning of the transect to sample the other side of the transect. The area sampled at random sites was 100 m².

Habitat Sampling

Each bed site and movement path was sampled for ground cover, soil characteristics, and canopy characteristics. Ground cover was sampled using a Daubenmire quadrat (Daubenmire 1959) with 6 categories (shrub, forb, grass, moss, bare ground, and water) along a 20 m transect. Transects extended 10 m in opposite directions from the center of the bed site or the beginning of the movement path. Soil and canopy measurements were taken at 0, 10, and 20 m on the transect. Soil measurements were taken by digging a shallow soil pit and measuring the depth of the litter and the depth of the duff (O_A and O_B soil horizons). Soil moisture was measured using a soil moisture meter (Merax, Model # KVOVMF7). The height of the ground vegetation at each of the points was measured with a measuring tape. Leaf-on canopy closure was estimated using a spherical densiometer (Forest Densiometers, Rapid City, South Dakota, USA) as described by Ward (2014). When using the densiometer after leaves had dropped off in the fall, all square corners of the densiometer within the bare branches of deciduous canopies were counted as closed. Canopies of understory shrubs taller than the observer were also included in densiometer readings. Densiometer readings were taken as if the

leaves were still on the tree to estimate canopy closure during the summer. Measurements taken facing each cardinal direction were averaged to estimate the total canopy closure.

Cover type of the sites was determined using a GIS analysis of the locations from the Land Use Land Cover data (MNDNR 2012). Mixedwood forests were areas of forest where the canopy is composed of approximately equal amounts of deciduous and conifer species. Deciduous forests were areas with at least 2/3 or more of the total canopy cover composed of deciduous species. Lowland conifer had marshes, fens, or peat bogs with high water content and a coniferous canopy component. Upland conifer stands were stands with at least 2/3 or more of the total canopy composed of conifer species and a low water table. Regenerating forests were created by natural disturbance or logging (MNDNR 2012). Recent timber harvests were identified visually because they are too recent to be recorded on satellite imagery. Prescribed fire treatment sites were burned 3-4 years before tick sampling.

Tick Counting

Bagged flannels were frozen (-20 C) upon return from the field for 2-14 days and removed from the freezer just before counting the ticks. Ticks were counted by slowly opening the flag on a large white bench. Each tick was counted as it was removed from the flag with tweezers. Ticks were placed on a tape labeled with collection site identification for future reference. The flag was folded in 4 – 6 cm strips to examine the front and back of the flag.

Statistics

Wilcoxon/Kruskal-Wallis rank sums tests, ANOVAs, Student's t-tests and

contingency analyses were completed with JMP Pro (version 10.0.0, SAS Institute Inc., Cary, North Carolina, USA). Normality of the data was tested with the Shapiro-Wilk test using RStudio (version 0.98.501, RStudio Inc., Boston, Massachusetts, USA). Tick densities were \log_{10} transformed because they were not normally distributed. The significance for 2014 litter depth and litter depth in cover types is reported using Wilcoxon/Kruskal-Wallis rank sums tests. ANOVAs were completed on all transformed tick density hypotheses and are reported for comparisons of tick densities between years, site type, litter depth, and canopy closure. Categorical data of tick presence in site type, litter depth, canopy closure, cover type, and temperature were analyzed with contingency tables. Statistical tests are reported using log likelihood ratios. Fisher's exact tests are reported for comparing the presence of ticks at random sites and moose locations as well as bed sites and movement paths. Student's t-tests were used to compare the averages of soil moisture, duff depth, vegetation height, and ground cover in sites with and without ticks. Values are expressed as means \pm standard error of the mean.

Results

We collected 32,986 ticks in 2013 and 12,717 ticks in 2014. Ticks were present in 54% of bed sites and movement paths in 2013 and 27% of sites in 2014. Tick density at bed sites and movement paths was lower in 2014 than in 2013 ($F_{1,77} = 14.3$, $p = 0.0003$, Fig. 1.3). Ticks were found at significantly more bed sites and movement paths than at random sites sampled in 2013 (Fisher's Exact Test, $p = 0.001$, Fig. 1.2). Ticks were present at only one of the 53 random sites sampled with a density of 7.7 ticks/m².

In 2013, bed sites had 21% of the ticks found. Ticks were present at 33% of the bed

sites with a density of 11.2 ± 6.3 ticks/m². In 2014, bed sites had 50% of the ticks found, and ticks were present at 26% of bed sites with a density of 3.1 ± 2.1 ticks/m².

Movement paths were 98 ± 2 m and 68 ± 0.2 m long in 2013 and 2014 respectively. Movement paths had 79% of the ticks collected in 2013. Ticks were present at 70% of movement paths with a density of 10.7 ± 7.5 ticks/m². More movement paths than bed sites had ticks present in 2013 (Fisher's Exact Test, $p = 0.01$). However, if ticks were present, tick densities were not significantly different between movement paths and bed sites ($F_{1,24} = 0.004$, $p = 1$). In contrast to 2013, tick density was similar in bed sites and movement paths in 2014 ($F_{1,51} = 0.04$, $p = 0.8$). In 2014, 50% of the ticks found were in movement paths and ticks were found at 27% of movement paths with a density of 2.5 ± 1.3 ticks/m².

Habitat Relationships

Ground cover, soil moisture, and duff depth were similar at sites with and without ticks in 2013 (Table 1.1). Cover type did not have a significant effect on tick densities in either 2013 or 2014 (2013: $F_{3,21} = 0.8$, $p = 0.5$; 2014: $F_{4,48} = 0.7$, $p = 0.6$), but there was a general trend toward higher tick densities in mixedwood, lowland conifer, and regenerating cover types. More than 50% of sites in both the lowland conifer and mixedwood cover types had ticks present in 2013. There was a significant difference in percent of sites with and without ticks by cover type in 2014 ($\chi^2_5 = 29$, $p = 0.0001$). Less than 20% of lowland conifer sites and 40% of mixedwood sites had ticks in 2014. Regenerating forests in 2014 had ticks present in over 70% of the sites. Ticks were not found at any of the 10 upland conifer sites sampled (Fig. 1.4).

Litter Depth

Tick density was higher in litter depths < 3 and > 9 cm in 2013 ($F_{3,22} = 2.9$, $p = 0.06$). In 2014, tick density was higher in litter depths < 3 cm ($\chi^2_3 = 13.9$, $p = 0.003$). Tick densities at sites with litter depths of < 3 cm were 20.9 ± 7.1 ticks/m² and 3.4 ± 2 ticks/m² in 2013 and 2014 respectively (Fig. 1.5). Litter depth varied among cover types in 2013 ($\chi^2_3 = 17.5$, $p = 0.0005$) with lowland conifer cover types having higher litter depths than those found in mixedwood and regenerating forest cover types. Litter depths ranged from < 3 to > 9 cm in mixedwood forests. When tick densities in mixedwood litter depths were examined separately, the highest tick densities in mixedwood forests were in litter depths < 3 cm in both years.

Canopy Closure

Closed canopies ($> 50\%$ closed) had lower tick densities than open canopies ($< 50\%$ closed) in both years (2013: $F_{4,21} = 8.1$, $p = 0.008$; 2014: $F_{3,49} = 15$, $p = 0.003$). Open canopies had 15.0 ± 4 ticks/m² and 30.2 ± 16 ticks/m² in 2013 and 2014 respectively (Fig. 1.6). Closed canopies had 2.8 ± 1.1 ticks/m² and 1.1 ± 0.4 ticks/m² in 2013 and 2014 respectively. A greater percentage of sites with more open canopies had ticks than closed canopies (Fig. 1.6). Sites where ticks were found had canopy closures of $39.0 \pm 6.1\%$ and $80.3 \pm 2.4\%$ and sites without ticks had canopy closures of 59.8 ± 6.7 and $90.1 \pm 1.0\%$ in 2013 and 2014 respectively (2013: $\chi^2_1 = 4.5$, $p = 0.03$; 2014: $\chi^2_1 = 15$, $p = 0.0001$). Although ticks were present at higher canopy closures, a decreasing trend in percent of sites with ticks and tick density occurred as canopy closure increased above 60% closure (Fig. 1.6). Canopy closure was not different among cover types in

either year (2013: $\chi^2_3 = 3$, $p = 0.3$; 2014: $\chi^2_5 = 10.4$, $p = 0.063$).

Plant Species

Ticks were collected from beaked hazel (*Corylus cornuta*), fern (*Dryopteris* spp.), mountain maple (*Acer spicatum*), Labrador tea (*Ledum groenlandicum*), raspberry (*Rubus idaeus*), grasses and sedges (*Poa* spp., *Carex* spp.), balsam fir (*Abies balsamea*), quaking aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*), cherry (*Prunus* spp.), red osier dogwood (*Cornus sericea*), and grey alder (*Alnus incana*) stems. Ticks were most frequently collected from 0.5 – 2 m tall beaked hazel and mountain maple and 0.25 – 1.5 m tall Labrador tea, ferns, and raspberries (Table 1.2).

Weather Conditions

Sites were identified from GPS locations of moose during the spring tick drop-off season. The sampled dates were from May 8 to May 23, 2013 and from May 4 to May 15, 2014. Average daily spring temperatures during the drop-off period ranged from 1 to 15 °C in 2013 and from 1 to 10 °C in 2014. The warmest spring temperatures were May 15-23, 2013 and May 6-14, 2014 (Fig. 1.7). The percent of sites where ticks were collected in the fall based on the drop-off date in May increased to mid-May both years, and then decreased until May 23, 2013 (Fig. 1.7). Percent of sites with ticks based on the spring drop-off temperature remained relatively constant with a slight decrease with temperatures above 10 °C in both years (2013: $\chi^2_3 = 0.05$, $p = 1$; 2014: $\chi^2_2 = 2$, $p = 0.3$, Fig. 1.7).

Similarly, the percent of sites with ticks was relatively constant at all sampling temperatures in the fall (2013: $\chi^2_2 = 1.1$, $p = 0.6$; 2014: $\chi^2_2 = 1.4$, $p = 0.5$, Fig. 1.7).

We continued checking for winter ticks in 2013 until November 26. Average daily temperatures were between -6 and -13 °C from November 16, 2013 and November 26, 2013. Winter ticks were still present on the vegetation with reduced activity. During this time period ticks were inactive unless warmed. Ticks were covered with several centimeters of snow on November 26, 2013, and we stopped sampling.

Discussion

Host behavior and host habitat selection influences tick survival and reproductive success. Moose use one area for an extended period of time for bedding. If ticks dropped off at a constant rate and survival and reproduction was similar in all habitats, bed sites would have higher larval tick densities than movement paths. Winter ticks do not drop off at a regular rate (Drew and Samuel 1989), but spring moose beds are often bloody and full of engorged female ticks (Wilkinson 1967, Samuel 2004). Bloody beds with a high concentration of engorged females are likely caused by the shaking, rubbing, and scratching by moose at beds (Geist 1963). Ticks prematurely dislodged by moose at bed sites when the tick is partially engorged produce fewer larval ticks (Drummond et al. 1969, Addison et al. 1979, Addison and Smith 1981, McLaughlin and Addison 1986, Barker 1990, Samuel 1991, Mooring and Samuel 1998). Even with the potentially large number of engorged ticks dropped at bed sites, there was no difference in larval tick density at bed sites and movement paths.

The habitat selected by moose for bed sites and movement paths affected winter tick survival and led to the difference in tick presence. Movement paths cover more area than bed sites, so engorged female ticks could drop onto a more diverse selection of

habitats. Each habitat could either increase or decrease the survival and reproduction of the winter tick. Moose move and forage in open canopies with early successional browse species often created by a disturbance (Peek et al. 1976, Lenarz et al. 2011). Engorged female survival and number of larvae per female are negatively correlated with canopy closure (Drew and Samuel 1986*a*, Aalangdong et al. 2001). The habitat characteristics selected for in some bed sites could reduce winter tick survival and reproduction. Moose select bed sites in sheltered areas for predator avoidance, thermal protection, and substrate (Renecker and Hudson 1989, Bowyer et al. 1999, McCann et al. 2013). The greater canopy closure at bed sites reduces tick survival and reproduction (Drew and Samuel 1986*a*, Aalangdong et al. 2001).

Winter tick densities in northeast Minnesota were affected by a variety of drop-off habitat conditions. Tick density and presence was not influenced by percent ground cover, duff depth, or soil moisture. These habitat variables were relatively homogeneous across the landscape and were not different in areas with and without ticks. Tick density and presence varied with litter depth, canopy closure, and cover type.

The temperature and humidity of the microhabitats in the layers below the ground surface influence engorged female survival and egg success (Drummond et al. 1969, Drew and Samuel 1986*a, b*). Ticks burrow through the litter layer to lay eggs in the duff layer (Drew and Samuel 1986*a*). The highest tick densities were found in litter depths < 3 cm. Shallow litter allows engorged ticks to burrow into the duff before adverse weather conditions or predation reduce their survival (Samuel 2004). Sufficient heating of the duff with retention of soil moisture in forested habitats is permitted with if litter depth is

shallow (Drew and Samuel 1986a). Additionally, high tick densities were found in some litter depths > 9 cm. All of the deep litter depths were in lowland conifer cover types where the temperature and humidity conditions below the surface must still have been favorable for tick survival and reproduction.

Winter tick densities were lower under high canopy closures, with highest tick densities found in canopies with less than 60% canopy closure. Engorged female ticks had slightly higher survival in open canopies than in closed canopies (Drew and Samuel 1985b, 1986a, Aalangdong 1994, Aalangdong et al. 2001). Additionally, females under open canopies produced 480 – 1,650 larvae per female compared to only 10 – 650 larvae per female under closed canopies (Aalangdong et al. 2001). An alternative explanation for increased tick presence and density in open canopies in this study is related to snow melt. Habitats with closed canopies were more likely to have residual snow that potentially reduced survival of engorged females (Drew and Samuel 1986a).

Relationships between cover type and tick density or presence have the greatest potential for describing tick survival across northeast Minnesota. Cover type data is available for the entire study area whereas fine scale habitat measurements are only available when collected by the researcher. Tick density and presence were highest in the cover types most used by moose and that make up 70% of the study area (Chapter 2). Similar habitats in Alberta had relatively high survival of engorged females that produced 10-1,900 larvae per female (Aalangdong et al. 2001). Given that the relationship between cover type and ticks applies to a majority of the habitat in Minnesota, much of the landscape has the potential to support high larval tick densities.

High presence of ticks in regenerating forest cover types is of particular concern for moose in winter tick range. Regenerating cover types are often used by moose because of large quantities of palatable primary-growth browse (Lenarz et al. 2011). Normal forestry practices of timber harvest and prescribed fire increase the amount of regenerating forest on the landscape, so an increasing amount of forest that supports tick presence is being created. Additionally, prescribed fire is used to reduce winter tick densities (Drew and Samuel 1985*b*). Depending on the prescription for the fire, prescribed fire may open understory and overstory canopy closures while reducing or removing litter and duff; all of which support ticks. Fire may reduce high tick densities, but because fire creates regenerating forests that moose use, it also creates a reservoir for high tick densities.

Questing larval ticks were found on a variety of vegetation. Previous research examined the climbing height of ticks (Drew and Samuel 1985*a*, McPherson et al. 2000), but little information exists on the type of vegetation larval ticks climb. Ticks were found on the main understory shrub at the site. The understory in these sites was generally a mixture of browse species (Ward 2014) that ranged in height from 0.5 - 2.5 m tall (Chapter 3). Ticks did not appear to select a particular species. Although climbing browse species should increase the likelihood of finding a host, the high occurrence of ticks on browse species is likely a matter of spring moose habitat selection rather than tick selection.

Cold temperature should decrease larval tick activity. Fall temperatures $> 0^{\circ}\text{C}$ did not reduce the recovery of ticks from sites. Sampling temperatures were below the threshold for active larvae ($> 10^{\circ}\text{C}$; Drew and Samuel 1985*a*), yet we still picked up ticks

with the flag sampling technique. Ticks monitored past the sampling period when temperatures fell below -5°C had delayed activity levels similar to larval ticks in Alberta (Drew and Samuel 1985a). Because live ticks were still collected on flannel flags at temperatures below -5°C , ticks could potentially acquire a host in northeast Minnesota into late December when average daily temperatures are at least that high (NOAA 2001-2010).

Survival of engorged females should increase with increasing spring temperatures. Larval ticks were found in the fall where all of the drop-off temperatures in the spring were above -5°C . Because temperatures above -15°C are favorable for female tick survival (Drew and Samuel 1986a), May weather was not expected to influence tick presence. Female tick survival is reduced when ticks drop onto snow (Drew and Samuel 1986a). Tick densities at drop-off sites created prior to snow melt should be examined as ticks at these sites may also be an important infection source for moose.

The period when ticks drop off and lay eggs that can survive may be longer than what was reported in Alberta. The length of the drop-off period was not directly measured in this study, but ticks found at bed sites or movement paths that occurred past May 15th could indicate a longer drop-off season. The reported drop-off period in Alberta and Ontario ends in early to mid-May (Drew and Samuel 1985a, 1989, Addison and McLaughlin 1988, Samuel 2007). Later drop-off dates for winter ticks in Minnesota could be a local adaptation to Minnesota's long winters (Addison and McLaughlin 1988). Further investigation of drop-off sites later into May and June are needed to confirm the length of the drop-off period in Minnesota.

Tick densities were significantly different between years. Winter tick population cycles lag a year behind weather patterns (Samuel 2007, Bergeron and Pekins 2014). Higher tick densities in 2013 were related to the warm snow-free spring of 2012. The spring of 2012 had early snow loss and warmer temperatures, similar to the spring before the last major moose die-off attributed to winter ticks in northeast Minnesota in 1991 when 46% of the moose population had tick-related alopecia in January (Samuel 2004). The snow-free time from tick drop-off to larval senescence was longer in 2012 than in 1990, but fewer moose mortalities probably occurred in 2013 than in 1990 due to reduced moose densities (Bergeron and Pekins 2014, Carstensen et al. 2014).

Fewer ticks were found at moose sites in 2014 than in 2013 although sampling effort was increased. Fewer larval ticks present in 2014 could be due to two years with long snow cover during the drop-off season (Drew and Samuel 1986*a*). Most of northern Minnesota is covered in snow when the heaviest females that potentially produce the most larvae drop off (Drew and Samuel 1986*a, b*, 1989, Barker 1990, Addison et al. 1998).

The differences in ticks found between 2013 and 2014 may also be related to the change in the location frequency used to identify bed sites and movement paths. This is particularly evident when observing the percentages of movement paths with ticks in 2013 and 2014. In 2013, 70% of movement paths had ticks while only 27% of movement paths had ticks in 2014. With 1 hour locations in 2014, we were less certain of the path walked by moose and had fewer known points per path. Similarly, we were less certain about bed site locations. More area not used by moose would have been sampled in 2014

which lowered tick density and reduced the likelihood of detecting ticks when present.

Collection of winter ticks by flag sampling was improved through the use of known moose locations compared to random sampling on the landscape. The percent of sites where ticks were encountered during random sampling of cover types within moose home ranges was negligible compared to the percent of bed sites and movement paths where ticks were found. Flag sampling for winter ticks is extremely time consuming and costly (Bergeron and Pekins 2014). However, with radiocollared moose we were able to sample 20 bed sites and movement paths in 10 hours, and get a reliable estimate of tick density throughout the range. Sampling at known moose sites was completed quickly, reducing the labor and cost.

Additionally, using known moose locations allowed us to identify tick densities in areas that are not known to have high tick densities. Larval ticks sampled at carcass sites and clear cuts have high densities (Drew and Samuel 1986a, Bergeron and Pekins 2014). High tick densities occur at carcass sites since the entire tick load is dropped in one location, but moose deaths are infrequent and only affect a small area (Drew and Samuel 1986a).

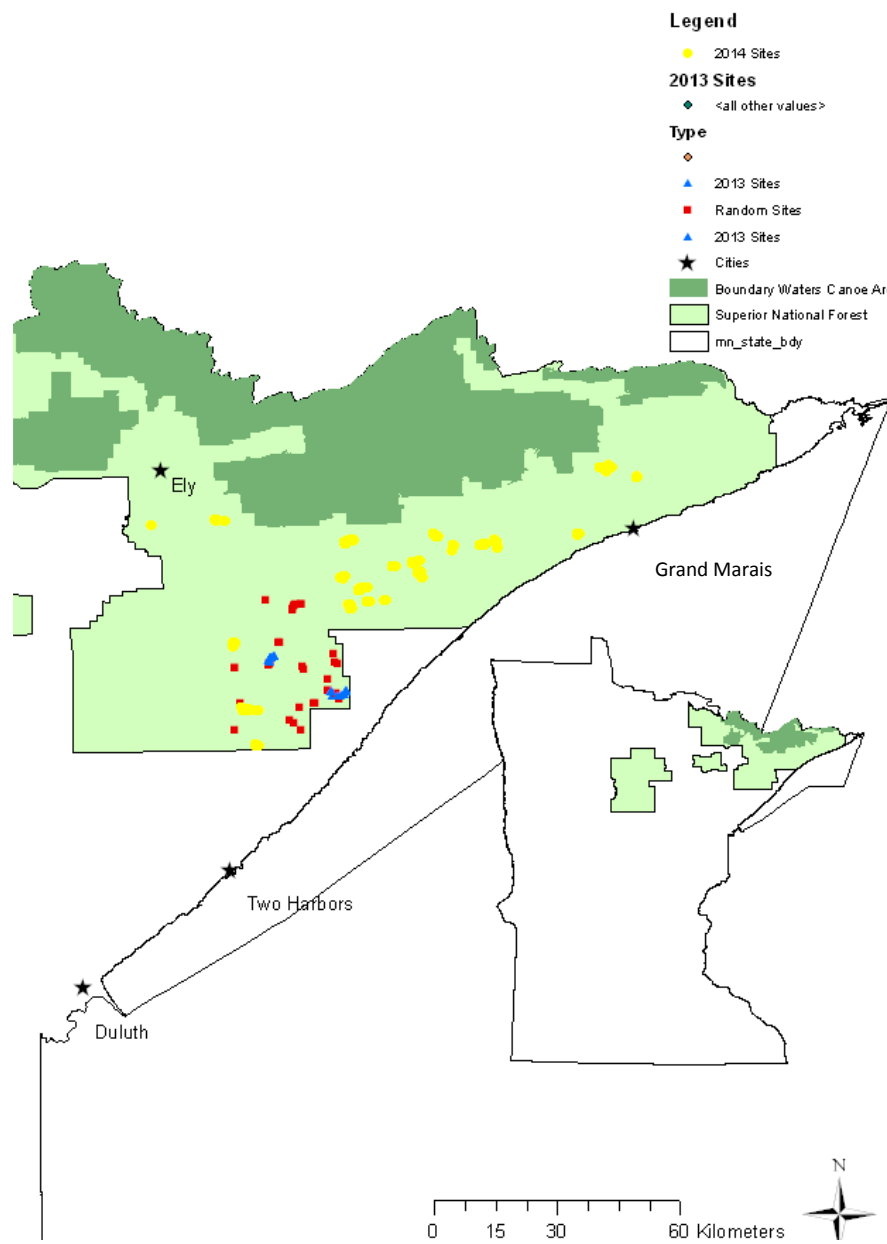


Figure 1.1. Study area.

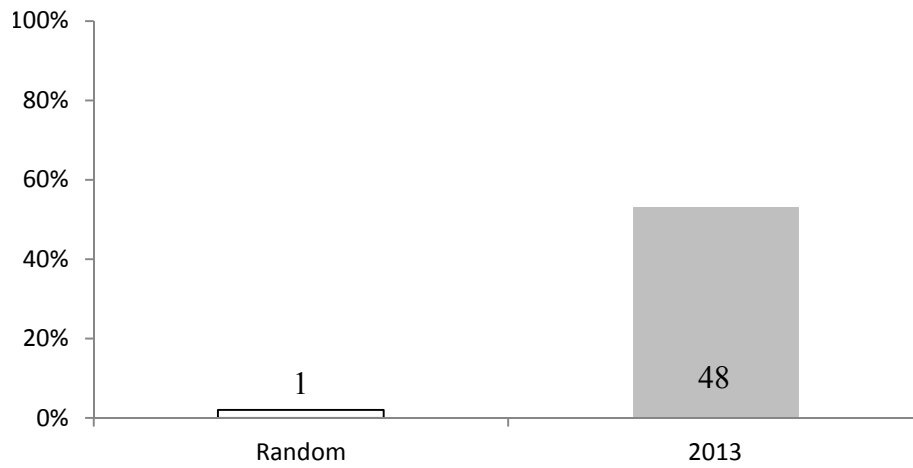
Table 1.1. Average microhabitat measurements (\pm SEM) at sites with and without winter tick larvae present. P values > 0.05 indicate a significant difference with a Student's t test with $df = 47$.

Micro Habitat Measurement	Units	Without ticks	With ticks	P value
Soil Moisture	%	6.5 ± 0.5	5.9 ± 0.5	0.72
Litter Depth	cm	4.9 ± 1	7.8 ± 1.5	0.06
Duff Depth	cm	34.9 ± 4.6	32.8 ± 3.4	1.00
Vegetation Height	cm	38.2 ± 6.1	34.2 ± 2.9	0.91
Canopy Closure	%	59.8 ± 6.8	31.1 ± 6.1	0.03*
Grass	%	18.5 ± 4.4	17.7 ± 3.3	0.63
Forb	%	22.3 ± 3	28.7 ± 3	0.11
Shrub	%	5.9 ± 1	4.1 ± 0.8	0.82
Moss	%	22.5 ± 4.9	22 ± 4.4	0.31
Bare Ground	%	24.9 ± 4.2	21.8 ± 3.7	0.52
Water	%	3.5 ± 1.9	0.6 ± 0.4	0.14

Table 1.2. Percent of times ticks were found on each species of vegetation (n = 95).

Species	Percent Occurrence
Beaked Hazel	25%
Fern	16%
Mountain Maple	13%
Labrador Tea	13%
Raspberry	12%
Grass	6%
Balsam Fir	5%
Quaking Aspen	4%
Paper Birch	2%
Cherry	2%
Red Osier Dogwood	1%
Grey Alder	1%

A) Percent of Sites with Ticks



B) Tick Density when Ticks are Present

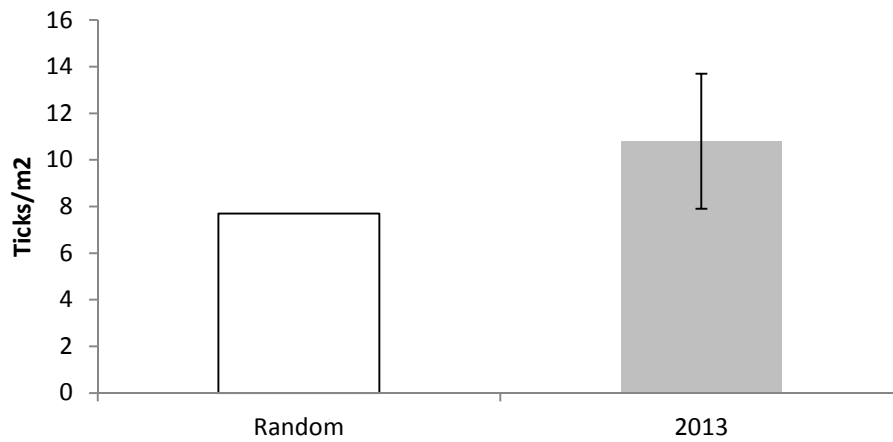
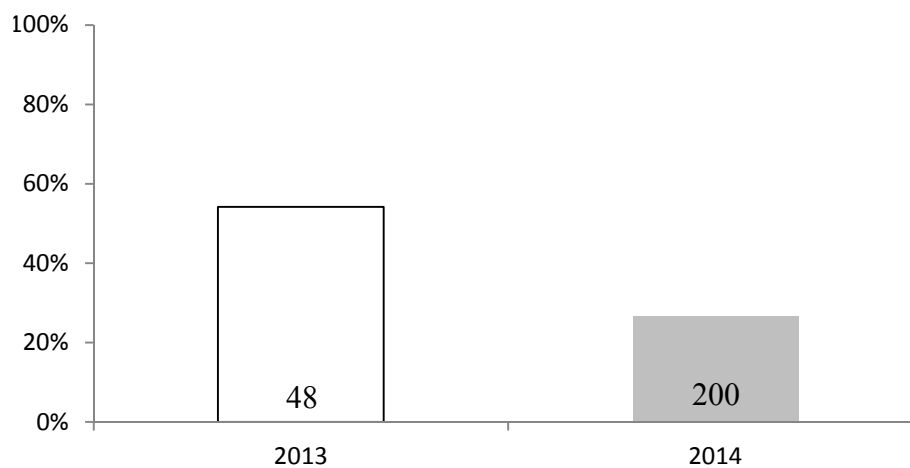


Figure 1.2. (A) Percent of random sites with ticks ($n = 1$) and moose use sites in 2013 with ticks. Sample size is given in the bar. (B) Tick densities in random cover types with ticks and moose use sites with ticks in 2013. Error bar represents 1 standard error of the mean.

A) Percent of Sites with Ticks



B) Tick Density when Ticks are Present

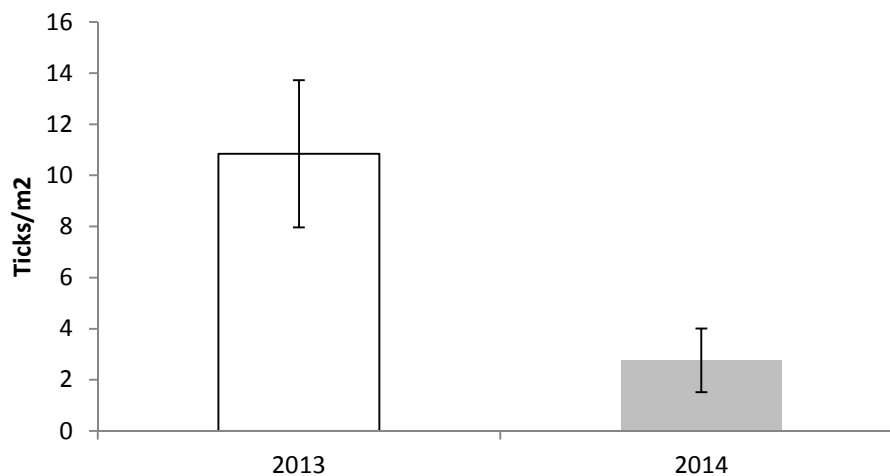
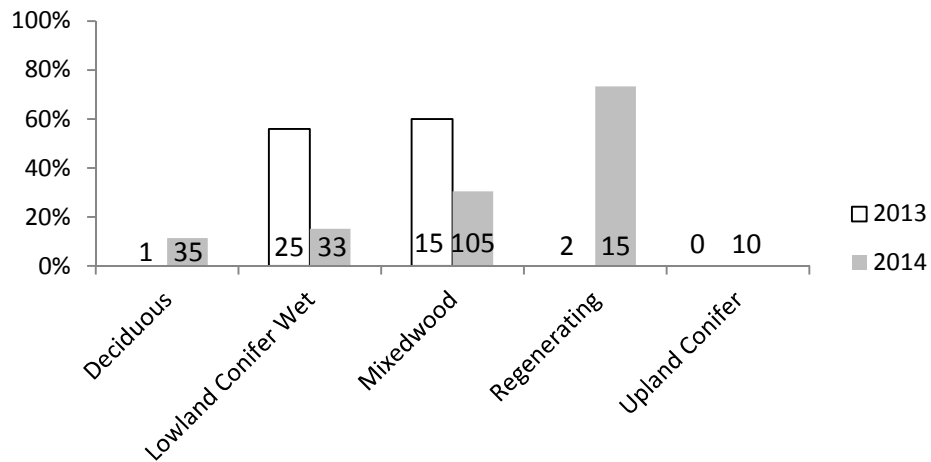


Figure 1.3. (A) Percent of sites in 2013 and 2014 with ticks and (B) tick density at sites with ticks. Sample size is given in the bar. Error bars represent 1 standard error of the mean.

A) Percent of Sites with Ticks



B) Tick Density when Ticks are Present

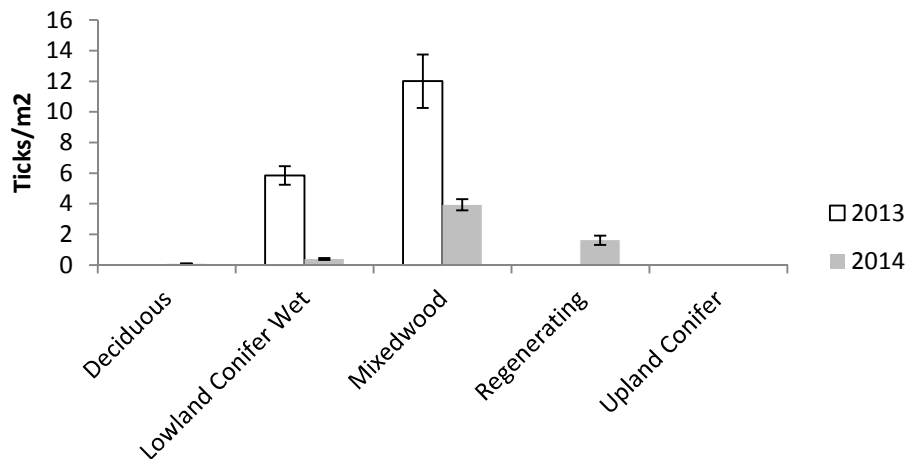
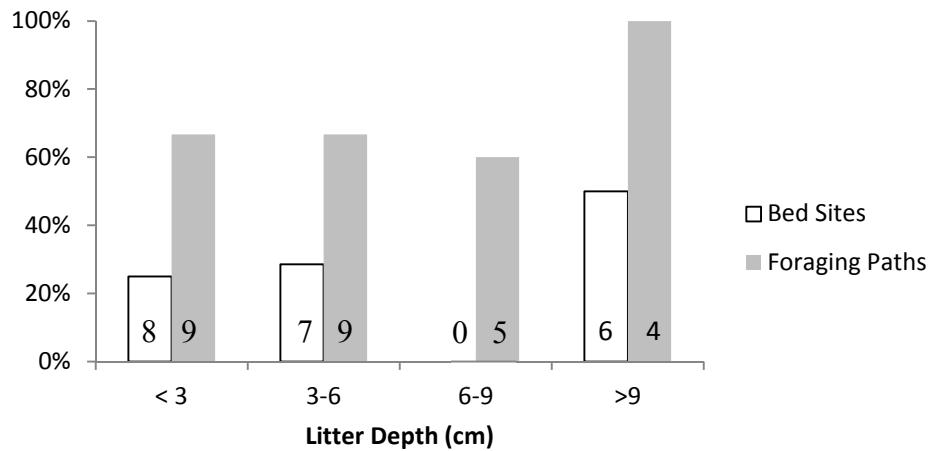


Figure 1.4. (A) Percent of 2013 and 2014 sites in each cover type with ticks. Cover types with less than 5 sites were excluded. Sample size is given in the bar. (B) Density of ticks in 2013 and 2014 in cover types where ticks were present. Error bars represent 1 standard error of the mean.

A) Percent of Sites with Ticks



B) Tick Density when Ticks are Present

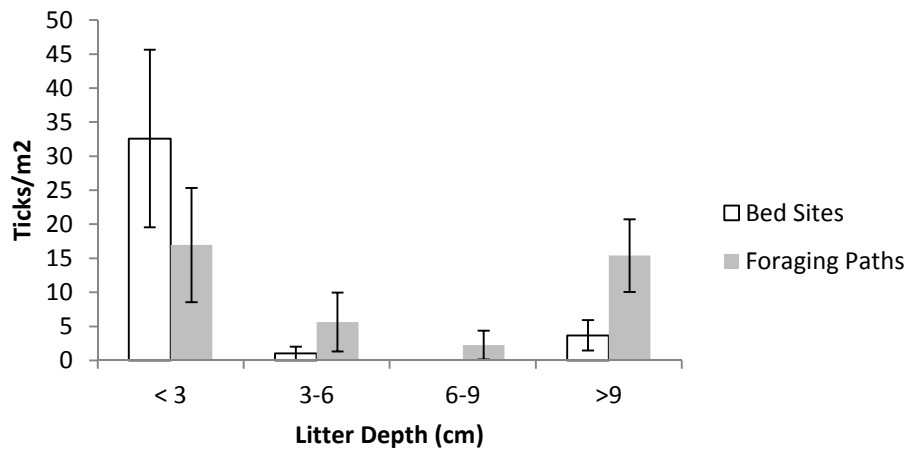
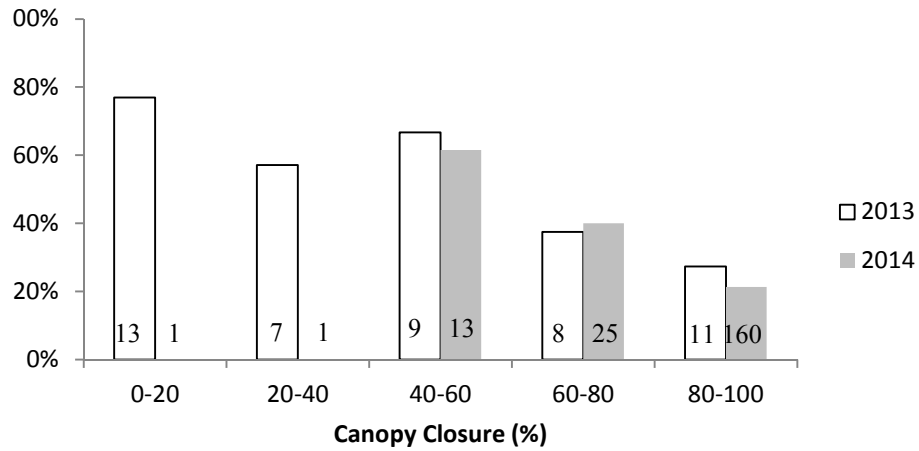


Figure 1.5. (A) Percent of sites with ticks by litter depth in 2013 and (B) tick densities in sites with ticks by litter depth in 2013. Sample size is given in the bar. Error bars represent 1 standard error of the mean.

A) Percent of Sites with Ticks



B) Tick Density when Ticks are Present

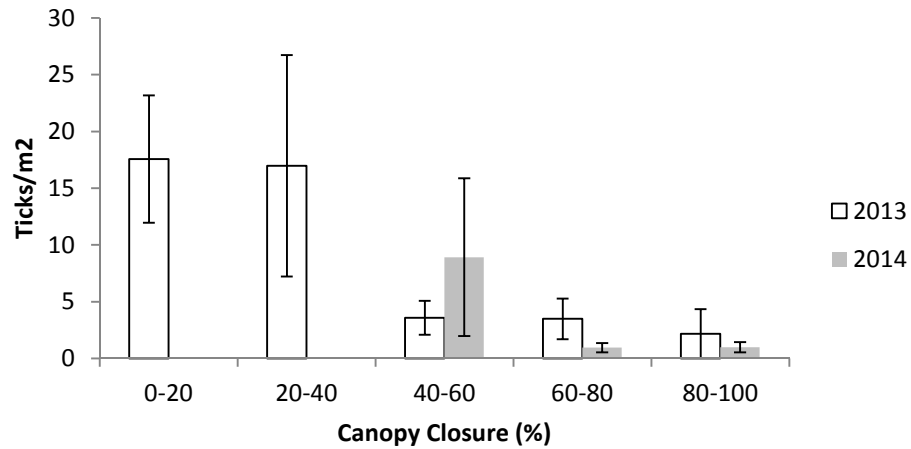
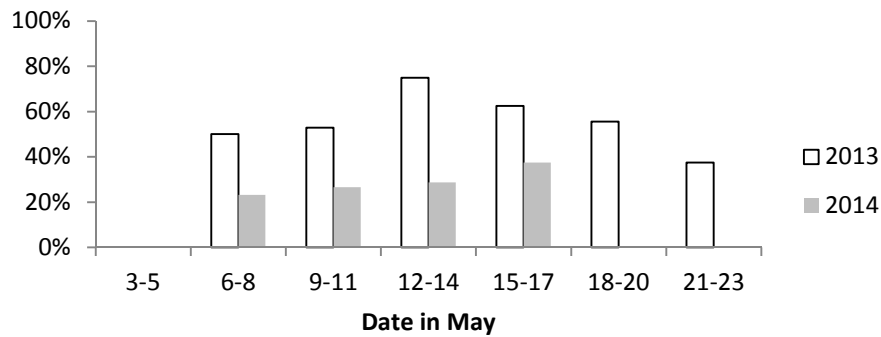
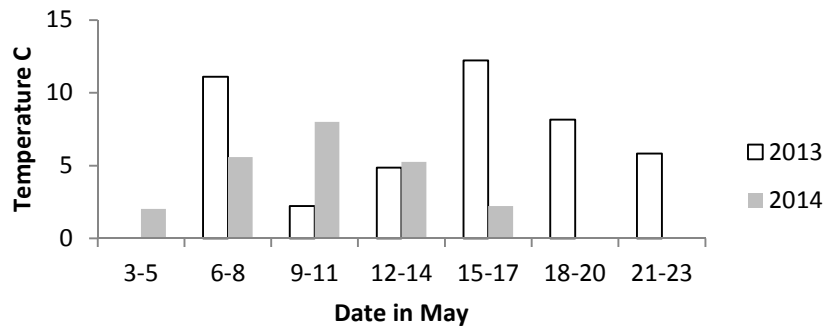


Figure 1.6. (A) Percent of sites in 2013 and 2014 with ticks by canopy closure. Percent of sites was only reported for categories with > 5 sites examined. Sample size is given in the bar. (B) Tick density by canopy closure for sites with ticks in 2013 and 2014. Error bars represent 1 standard error of the mean.

A) Percent of Sites with Ticks by Drop-off Date



B) Temperature at May Drop-off Date



C) Percent of Sites with Ticks by Temperature at Drop-off

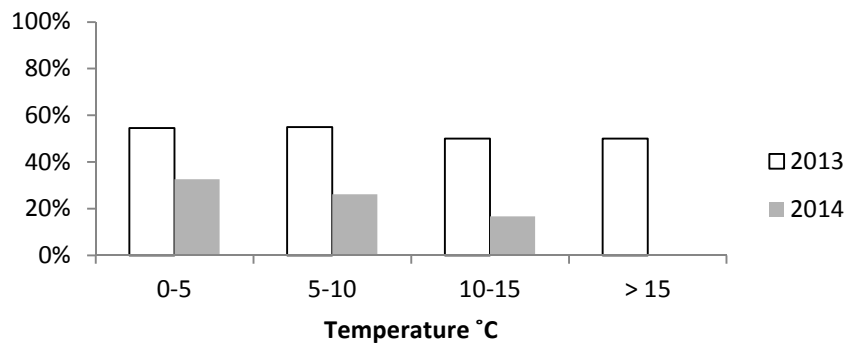


Figure 1.7. (A) Percent of sites where ticks were found by drop-off date in 2013 and 2014. (B) Temperature at the drop-off date in 2013 and 2014. (C) Percent of sites where ticks were found by drop-off temperature in 2013 and 2014.

Chapter 2: The Extent of Overlap between Spring and Fall Moose (*Alces alces*)

Paths

Introduction

Parasite survival relies on coming into contact with a new host. Many parasites are transferred from one animal to another through the use of the same habitat. Ticks drop from their hosts into the environment before finding a new host for at least one stage in their life cycle (Falco and Fish 1992, Burg 2001, Schulze et al. 2011). The environment that the tick drops into influences the species of new hosts that will be available to a tick (Horak et al. 2006, Dallas and Presley 2014). Host use of the environment where off-host ticks are located influences tick densities on the host (Barnard 1981, Burg 2001, Horak et al. 2006, Leu et al. 2010, Dallas and Presley 2014, Heylen et al. 2014). The probability of coming into contact with a new host is reduced when there is a delay between dropping from one host and acquiring another.

Winter ticks (*Dermacentor albipictus*) are an example of a parasite that experiences a delay before searching for a new host. Adult female winter ticks drop off their hosts in the spring and larvae that hatch in the summer search for a new host in the fall (Mooring and Samuel 1998, 1999, Samuel 2004). Host searching does not occur during the summer while eggs are incubating and hatching (Drew and Samuel 1985*a, b*, 1986*a*, Mooring and Samuel 1998).

Infested hosts first seed the habitat with female ticks from late March to Early May (Samuel et al. 2000, Drew and Samuel 1989, McPherson et al. 2000). Female tick survival is reduced at temperatures $< -5^{\circ}\text{C}$ or when females drop onto snow (Drew and Samuel 1986). Surviving females lay eggs in late May to early June (Drew and Samuel 1986*a*, McPherson et al. 2000). Eggs hatch into larvae in late August or early September

(Drew et al. 1985).

Larval ticks climb vegetation and quest for a host from early September to November (Addison et al. 1979, Drew and Samuel 1985, and McPherson et al. 2000).

The larvae attach to a host until temperatures drop below -10 °C and as long as they are not covered with snow (McPherson et al. 2000, Samuel 2007). Without early snows or low temperatures, larvae survive and quest up to 3-4 months under field conditions (Drew and Samuel 1985).

During the winter tick questing period, larvae attach to hosts such as cattle (*Bos taurus*), horses (*Equus caballus*), white-tailed deer (*Odocoileus virginianus*), mule deer (*O. hemionus*), elk (*Cervus elaphus*), caribou (*Rangifer tarandus*), and moose (*Alces alces*) (Drummond et al. 1969, Welch et al. 1991, Mooring and Samuel 1998, 1999, Samuel 2004). Moose are the most severely affected host in the northern winter tick range, with individuals acquiring 10,000 to > 100,000 ticks in Alberta and New Hampshire (Drew and Samuel 1985a, Mooring and Samuel 1998, Bergeron and Pekins 2014). Moose carrying low tick loads exhibit few symptoms. Large tick loads can lead to alopecia, infection, anemia, and death (Drew and Samuel 1989, Samuel 1991, McLaughlin and Addison 1996, Mooring and Samuel 1999, Musante et al. 2007).

In order to understand why winter tick infestations are so severe on moose, it is important to identify factors that influence larval transfer. Because moose only pick up ticks when they are in areas used by an infested host in the spring, identifying habitats that are used by moose in both the spring and the fall will increase the knowledge about where moose acquire large tick loads annually.

We used locations collected in 20-min intervals by GPS collars on moose in northeast Minnesota. Locations every 20 min gave a near linear path of moose that has never been available before. By using these locations we identified areas of overlap between moose paths during the drop-off and questing periods of winter ticks. The objectives of this study were to: 1. compare areas of spring and fall paths for male and female moose; 2. determine the average area of overlap between spring and fall moose locations; 3. identify the potential sources of overlap; and 4. identify the cover types where overlap most often occurs.

Methods

Study Area

This study took place in the same study area as Lenarz et al. (2009) in the arrowhead region of northeast Minnesota (47°30'N, 91°21'W; Fig. 2.1). Much of the study area is part of the Superior National Forest. The study area has a humid continental climate with severe winters and short dry summers. Precipitation occurs in the form of snow (180 cm annually) and rain (70 cm annually), 40% of which occurs during the plant growing season (NOAA 2001-2010). Snow cover is typically present from December through April. The soil is influenced by the Laurentian glacial shield with poorly drained soil that supports sedges (*Carex* spp.), Labrador tea (*Ledum groenlandicum*), black spruce (*Picea mariana*), white cedar (*Thuja occidentalis*) and tamarack (*Larix laricina*). Lakes and wet areas are surrounded by grey alder (*Alnus incana*) and red osier dogwood (*Cornus sericea*) that transitions into upland mixedwood forests (MNDNR 2014). Upland vegetation consists of fire-dependent forests dominated by a mix of eastern white and red

pine (*Pinus strobus* and *P. resinosa*), quaking aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*), white spruce (*Picea glauca*), and balsam fir (*Abies balsamea*).

Weather Conditions

Temperature and snow cover for 2011 and 2012 were determined using the methods described in Chapter 1. Spring drop-off dates and fall questing dates were identified during snow free periods in 2011 and 2012 (Table 2.1). The study area was divided into the northern part (north of Grand Marais) and southern part (south of Grand Marais, Fig. 2.1) to match geographically different snow free periods.

Moose Locations

We used 20-min GPS locations from the moose in this study. In 2011 we had 13 female and 5 male moose and in 2012 we had 8 female and 3 male moose. Moose wore Lotek Iridium GPS collars (Lotek Wireless, Inc., Newmarket, Ontario Canada). We selected all locations during the snow-free drop-off period and questing period in both years for each moose (Table 2.1). Locations for each moose were connected as a line.

Analysis of Overlap and Habitat Composition

The Geospatial Modeling Environment (Spatial Ecology LLC) and ArcMap were used to buffer the linear paths, and measure overlap of the spring and fall lines. The area used and the area of overlap in both spring and fall was determined. To estimate the potential for tick transmission, it was assumed that buffered paths in the spring could give ticks. Moose with buffered fall paths that overlapped buffered spring paths could potentially acquire ticks. The number of moose, gender of moose, and area of overlap were recorded for each moose that could have potentially gave or potentially acquired

ticks from overlapping paths. When a moose's spring path overlapped its own fall path, the overlap was considered a self-overlap. Cover type for overlapping areas and for the overall spring and fall paths was identified from the Land Use Land Cover (DNR Data Deli 2012) for northeast Minnesota (Chapter 1). The bog, marsh, and fen cover types were combined and are referred to as wet cover type.

Statistics

Statistical tests were completed with JMP (SAS Institute Inc., Cary, North Carolina, USA). ANOVAs were used to compare the types of overlap and the extent of overlap within the cover types. Student's t-tests were used to compare lengths of paths. Tukey's HSD was used to for comparisons of multiple means. A compositional analysis of habitat use was completed using adehabitatHS in RStudio (version 0.98.501, RStudio Inc., Boston, Massachusetts, USA). Values are expressed as means \pm standard error of the mean.

Results

The total study area encompassed 55,278 ha of which 5 cover types comprised 96% of the area. The cover type composition of the study area was 43% mixedwood forest, 15% wet, 16% conifer forests, 13% regenerating forests, and 8% deciduous forests.

Buffered fall paths covered significantly more area than buffered spring paths ($t_{65} = 4.8$, $p = 0.0001$) and buffered male fall paths covered significantly more area than buffered female fall paths ($t_{27} = 4.3$, $p = 0.0001$, Table 2.2).

All moose had buffered fall paths that overlapped with buffered spring paths. The overlapping area between buffered spring and fall moose paths in 2011 and 2012 was 3.1

± 0.4 ha ($n = 18$) and 2.2 ± 0.5 ha ($n=11$) respectively. The overlap accounts for 13% of the average buffered spring path in 2011 and 6% of the average buffered spring path in 2012. Overlap occurred in all of the 5 cover types, but occurred in a proportion that differed from what was available on the landscape ($\lambda = 0.4, p = 0.002$). Overlaps occurred in significantly more wet cover types areas than were available in the study area.

Moose self-overlapped over 1.1 ± 0.1 ha in each year which is similar to the amount of area a moose potentially gave ticks or potentially acquired ticks from other moose ($F_{2,27} = 0.8, p = 0.9$, Fig. 2.2). All moose self-overlapped. Self-overlap of males and females were similar ($t_{27} = 0.5, p = 0.3$). Self-overlap accounted for 4.3% of the spring path in 2011 and 3.5% of the spring path in 2012 (Table 2.3). Self-overlap was different among cover types ($F_{4,25} = 6.2, p = 0.0002$). Self-overlap occurred more in mixedwood forest cover types than in other cover types except for the wet cover type.

In 2011, 88% ($n = 18$) of moose potentially gave ticks to other radiocollared moose and 72% ($n = 11$) of moose potentially gave ticks to other radiocollared moose in 2012. Moose potentially gave ticks to other moose on 1.0 ± 0.3 ha. The area where moose potentially gave ticks to other moose accounted for 5.3% of the spring path in 2011 and 1.5% of the path in 2012. The overlap where moose potentially gave ticks to other moose was greater in mixedwood cover types than in other cover types except wet (Fig. 2.3).

In 2011, 71% of moose potentially acquired ticks from other radiocollared moose and 43% ($n=11$) of moose potentially acquired ticks from other radiocollared moose in 2012. Moose potentially acquired ticks from other moose on 1.1 ± 0.2 ha. Moose

potentially acquired ticks from other moose over 2.1% of the fall path in 2011 and 1.7% of the fall path in 2012 (Table 2.3). Fall paths crossed spring paths more in mixedwood forests than in deciduous forests ($F_{4,27} = 2.9$, $p = 0.03$).

Discussion

The overlap between spring and fall moose paths accounts for a small percentage of the spring movement path. The total overlap of paths with paths from other moose would be higher because not all of the moose in the area were collared. Additionally, high density moose populations could increase the amount of overlap from other moose. When moose populations were at high densities, female moose shared 33% of their individual home range with other moose (Cederlund and Okarma 1988). High overlap of female home ranges could lead to a moose's fall path overlapping more with another moose's spring path. Self-overlap would be the minimum overlap of spring and fall paths a moose experience, and the maximum overlap is unknown due to the uncertainty of overlap from non-collared moose.

The small percentage of overlap of spring and fall paths could be attributed to moose avoiding winter ticks. Some evidence exists that moose may avoid areas with winter ticks. Moose and cattle become agitated and avoid pelleted rations or pastures when they observe winter ticks (Welch et al. 1991, Samuel et al. 2000, Samuel 2004). As such, moose may avoid areas when they detect winter ticks on the vegetation. However, clumps of ticks are difficult to detect; it is more likely that overlap is not driven by ticks but by seasonal habitat requirements of moose.

If moose pick up ticks from the environment with the same percentage as flag

sampling (16%, Drew and Samuel 1985a), moose could potentially acquire high tick loads from the small area of self-overlap alone. Even the average tick load of 10,000 ticks in Alberta, Canada (Drew and Samuel 1985a) could be collected in both low and high tick density years. Self-overlap in low tick density years with 2.8 ticks/m² (Chapter 1) could result in tick loads of over 16,000 ticks. High tick density years with 10.8 ticks/m² (Chapter 1) could result in tick loads of over 64,000 ticks. The number of ticks collected annually could increase or decrease with the influence of habitat.

The cover types most used by moose may increase tick transmission risk. Cover types in northeast Minnesota with the highest tick densities and tick presence were mixedwood forest, lowland conifer (wet), and regenerating forest (Chapter 1). Overlap occurred in all of the examined cover types, but was the greatest in mixedwood and wet cover types. Mixedwood and wet cover types make up 60% of the study area and 43% of moose locations in this study. Many cows moved from mixedwood cover types to wet cover types for birth sites and post parturition sites (McGraw et al. 2011, 2014). More overlap occurring in wet cover types than is available on the landscape could be related to the increased use of wet cover types by cows in the spring after parturition.

Spring and fall paths differed for males and females. Spring paths covered less area than fall paths due in part to the shorter time period measured in the spring and the longer time period measured in the fall. In the spring, parturition occurs around May 14th (McGraw et al. 2014) at the end of the winter tick drop-off period. Female spring paths were shorter as cows with calves are more sedentary following parturition (McGraw et al. 2011). In the fall, male paths covered more area than female paths. Longer male fall paths

are expected because of movements during the rut. The rut occurs from September 7 to October 22 (Phillips et al. 1973, Leblond et al. 2010) when peak numbers of larvae are questing on the vegetation (McPherson et al. 2000). During this time females are more sedentary while males increased movement rates while searching for cows (Van Ballenberghe and Peek 1971, Phillips et al. 1973, Cederlund and Sand 1994).

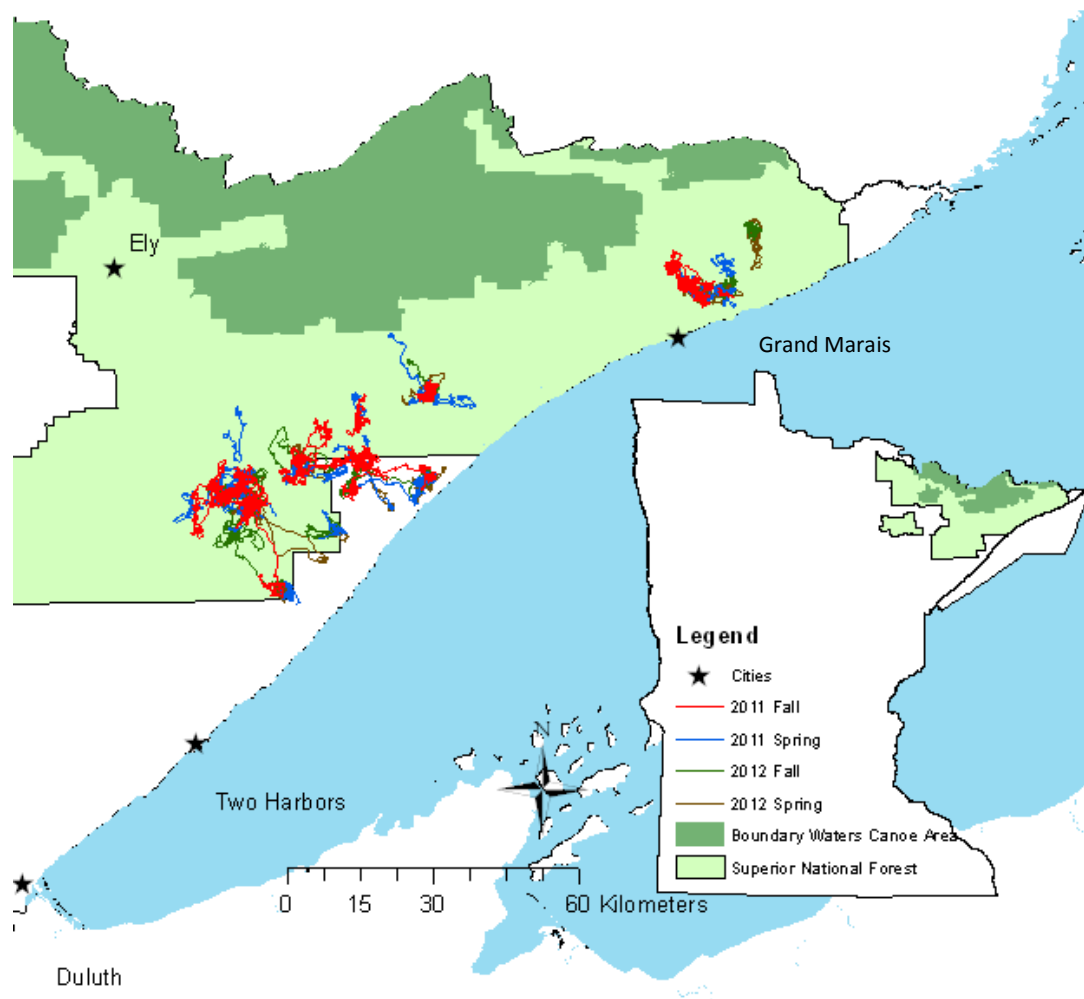


Figure 2.1. Study area

Table 2.1. Spring drop-off and fall questing dates and duration in 2011 and 2012.

	2011		2012	
	Dates	Days	Dates	Days
Southern Drop-off	May 5 – May 15	10	April 1 – May 15	45
Southern Questing	Sept. 15 – Nov. 18	64	Sept. 15 – Nov. 23	69
Northern Drop-off	April 25 – May 15	20	April 24 – May 15	19
Northern Questing	Sept. 15 – Nov. 18	64	Sept 15 – Nov. 23	69

Table 2.2. The average area of the buffered spring movement path in 2011 and 2012 and the average area of the buffered fall paths for 2011 and 2012. Buffered fall paths are also separated into male and female buffered fall paths for 2011 and 2012.

Year		Area (ha)	SEM	N
2011	Spring	23	2	24
2011	Fall	55	5	19
2011	Female	45	4	13
2011	Male	76	9	6
2012	Spring	39	3	14
2012	Fall	46	9	11
2012	Female	34	5	7
2012	Male	74	24	3

Table 2.3. The percent of overlap with the spring paths and fall paths in 2011 and 2012.

	% of Spring Path Self Overlap	% of Spring Path Gave Overlap	% of Fall Path Acquired Overlap
2011	4.3	5.3	2.1
Female	4.2	4.1	3.1
Male	4.6	7.9	0.8
2012	3.5	1.5	1.7
Female	4.3	1.9	3.0
Male	1.9	0.0	0.4

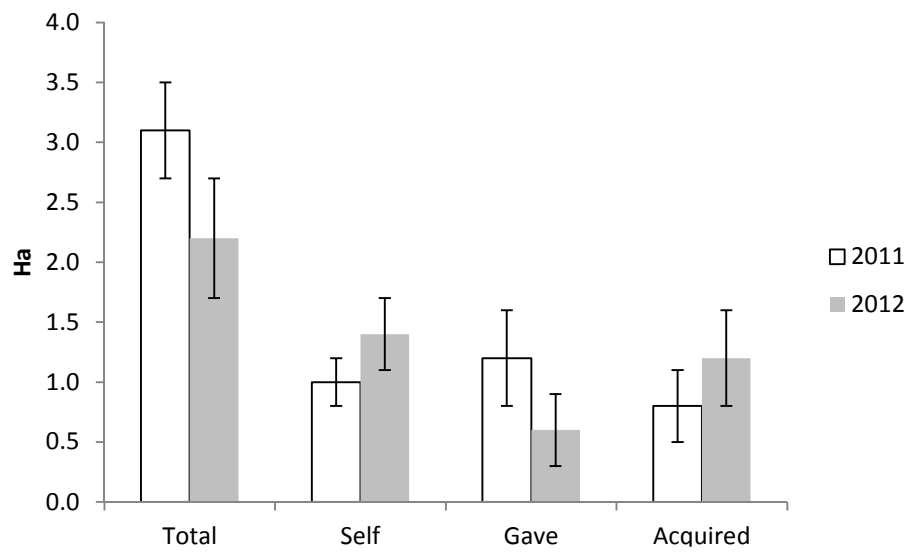


Figure 2.2. Area of overlap (ha) for self overlap, potentially gave, and potentially acquired in 2011 and 2012.

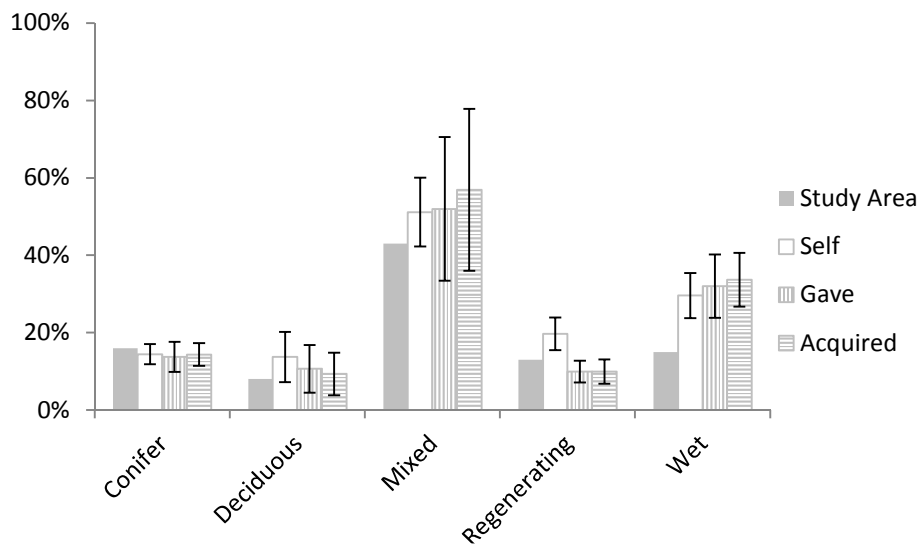


Figure 2.3. Percent of habitat composition in the study area, self, potentially gave, and potentially acquired overlap areas.

**Chapter 3: Comparison of Flagging and Walking Surveys on Winter Tick
(*Dermacentor albipictus*) Sampling Density**

Introduction

Accurate abundance monitoring must occur to properly assess risks imposed by parasites. Winter ticks (*Dermacentor albipictus*) can parasitize moose. Tick loads of more than 10,000 ticks cause morbidity and mortality (Drew and Samuel 1985a, Mooring and Samuel 1998, Bergeron and Pekins 2014). Monitoring winter tick abundance on the southern edge of moose distribution could help develop or inform management strategies to prevent potential mass die-off's of moose (*Alces alces*), or targeting management treatments in areas with high tick densities (Samuel 2007).

Periodic die-offs of moose across North America have resulted from tick infestations of moose (Samuel 2004). Monitoring techniques for winter ticks include tick drags, hide digestion, and hair-loss surveys (Drew and Samuel 1985a, Welch and Samuel 1989, Samuel 1991, Mooring and Samuel 1999, Bergeron and Pekins 2014). Elk Island National Park in Alberta, Canada monitors with hide digestions (Welch and Samuel 1989), and managers in New Hampshire perform roadside hair-loss surveys (Bergeron and Pekins 2014). Hide digestion monitoring is only a viable option if moose are harvested. Roadside hair-loss surveys are not feasible if moose do not congregate at easily accessible roadside salt licks. Aerial surveys occur in Minnesota in January (DelGiudice 2014), when hair loss from winter ticks is not very visible (Samuel 1991).

The most common off-host monitoring strategies are tick drag and flag surveys, which employ a flannel cloth attached to a dowel that is dragged behind or beside the surveyor (Carroll and Schmidtman 1992, Castro and Clover 2010, Dantas-Torres et al. 2013). No off-host monitoring strategies other than tick flag and drag surveys have been

employed on winter ticks. Other off-host tick sampling methods exist, although they may not be feasible for winter tick surveying. Many other species of ticks are surveyed with CO₂ baited traps, visual surveys, and walking surveys (Carroll and Schmidtman 1992, Falco and Fish 1992, Castro and Clover 2010, Dantas-Torres et al. 2013). CO₂ traps are impractical because winter ticks do not travel once they climb the vegetation (Drew and Samuel 1985a, McPherson et al. 2000) and would not move towards the CO₂ trap. Although large clumps of winter tick larvae can be visible on vegetation, they are easily overlooked and difficult to find in thick vegetation which would make visual surveys challenging. Conventional tick drag surveys could be employed to monitor winter tick abundance. A final alternative tick monitoring strategy of walking surveys could be a viable option. Walking surveys provide the stimuli of odor, vibration, vision, touch, and heat that stimulate larvae to actively quest for a host (Drew and Samuel 1985).

We compared tick flag surveys and walking surveys with flannel chaps to survey for winter ticks. We wore flannel chaps and dragged flags on the same transects for a direct comparison of the two methods. The objectives of this study were to: 1. compare flag surveys and walking surveys for collecting winter ticks; 2. identify heights of questing ticks; and 3. characterize the height of the vegetation in northeast Minnesota.

Methods

Study Area

This study took place in the same study area as Lenarz et al. (2009) in the arrowhead region of northeast Minnesota (47°30'N, 91°21'W; Fig. 3.1). Much of the study area is part of the Superior National Forest. The study area has a humid continental

climate with severe winters and short dry summers. Precipitation occurs in the form of snow (180 cm annually) and rain (70 cm annually), 40% of which occurs during the plant growing season (NOAA 2001-2010). Snow cover is typically present from December through April. The soil is influenced by the Laurentian glacial shield providing poor draining soil that supports sedges (*Carex* spp.), Labrador tea (*Ledum groenlandicum*), black spruce (*Picea mariana*), white cedar (*Thuja occidentalis*) and tamarack (*Larix laricina*). Lakes and wet areas are surrounded by grey alder (*Alnus incana*) and red osier dogwood (*Cornus sericea*) that transitions into upland mixedwood forests (MNDNR 2014). Upland vegetation consists of fire-dependent forests dominated by a mix of eastern white and red pine (*Pinus strobus* and *P. resinosa*), quaking aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*), white spruce (*Picea glauca*), and balsam fir (*Abies balsamea*).

Moose Site Identification

GPS locations were collected every hour from 20 female moose (Carstensen et al. 2014). Moose were wearing Vectronics Iridium GPS collars (Vectronics Aerospace, Berlin, Germany). Moose locations from May 2014 were visually examined using ArcMap 10.1 (ESRI, Redlands California, USA) and bed sites and movement paths were identified (Chapter 1).

Tick Flag and Chap Creation

Flags were made by cutting 1.0 x 1.15 m of white flannel fabric. The fabric was rolled onto the end of a 1.5 m long 0.6 cm-PVC conduit until 1.0 m² of fabric remained free flowing. Three large paper clamps were used to secure the flag onto the conduit.

Chaps were created by making a belt out of nylon webbing and side release buckles. A 1.0 x 1.15 m of white flannel fabric was cut and a 0.7 m slit was cut in the middle of the 1.0 m edge of the fabric. Chaps were attached to the belt by tucking 0.15 m of fabric on the opposite side of the slit under the belt. Fabric was wrapped around the legs and held in place with rubber bands.

Survey for ticks

Ticks were sampled by visiting identified bed sites and movement paths from September 17 to October 18, 2014. Sites were sampled by carrying the flag on the right side of the body and dragging it across the top of the vegetation while keeping the greatest surface area of the flag in contact with the vegetation. Chaps were worn while walking through the site to sample ticks with the flag. The flag did not cover the chaps during sampling so that the entire surface of the chaps was available to collect ticks from the vegetation. Sampling at bed sites started at the center of the bed. Chaps were worn and flags were dragged as the surveyor walked in 5 concentric circles at 0, 1, 2, 3, and 4 m from the center of the bed. The area sampled at a bed site was 78.5 m² with the flag and 39.25 m² with chaps.

At movement paths, chaps were worn and flags were dragged as the surveyor walked from point to point in chronological order. At the end of the movement path, the surveyor walked back to the beginning of the path to make a sampling width of 2 m with the flag and 1 m with the chaps. The area of movement paths was determined by the distance walked times the sampling width. Because of GPS error (Moen et al. 1996, 1997) and the uncertainty of the movement of the moose between locations, the area

sampled did not follow the moose's path exactly. Tick densities were determined by dividing the total number of ticks found at the site by the area sampled.

When ticks were found on either the flag or the chaps at the end of the movement path or bed site sampling, both were collected and folded to maintain the position of clumps on the chaps. Folded flags and chaps were placed in separate labeled Ziploc® bags. If ticks were not found, clinging vegetation was picked off and both the flag and chap were re-used. Collected flags and chaps were frozen upon return from the field.

Habitat Data

The average heights were estimated for grass, forbs, low shrubs, and tall shrubs at the center of the bed or movement path and 10 m to both sides of the center. Cover type of the sites was determined using a GIS analysis of the locations from the Land Use Land Cover data (MNDNR 2012). Mixedwood forests were areas of forest where the canopy is composed of approximately equal amounts of deciduous and conifer species. Deciduous forests were areas with at least 2/3 or more of the total canopy cover composed of deciduous species. Lowland conifer had marshes, fens, or peat bogs with high water content and a coniferous canopy component. Upland conifer stands were stands with at least 2/3 or more of the total canopy composed of conifer species and a low water table. Regenerating forests were created by natural disturbance or logging (MNDNR 2012).

Tick Counting

Flannel flags and chaps were removed from the freezer just before counting and placed on a large white bench. Chaps were examined for the height (from the slit side) of the highest clump, lowest clump, and the greatest number of ticks. The flag was divided

into 33.3 cm sections, the lower 1/3, the middle 1/3, and upper 1/3. Tick numbers in each section were recorded. The total number of ticks for the chaps was found by adding the tick totals for each of the sections. Only the total number of ticks collected with the flag was recorded. Ticks were removed from the fabric as they were counted.

Statistics

Statistical tests were completed with JMP (SAS Institute Inc., Cary, North Carolina, USA). Tick densities between the sampling techniques were evaluated using a paired t-test. Comparisons of vegetation height within cover types were made using ANOVAs. Multiple means were compared using Tukey's HSD. Categorical data were analyzed with contingency tables with χ^2 Likelihood ratios. Values are expressed as means \pm SEM.

Results

Ticks were collected from 100 bed sites and 100 movement paths. Sites with ticks had a density of 2.8 ± 1.2 ticks/m² with both sampling techniques combined. Bed sites had 6,315 ticks which accounted for about 50% of the total ticks. Ticks were found at 26% of bed sites with a density of 3.1 ± 2.1 ticks/m² with both sampling techniques combined. Movement paths had 6,402 ticks which accounted for about 50% of the ticks found. Ticks were found at 27% of movement paths with a density of 2.5 ± 1.3 ticks/m² with both sampling techniques combined.

Of the 53 sites where ticks were found, ticks were collected with flags at 89% of the sites with a density of 1.9 ± 1.0 ticks/m². With chaps, 94% of the sites had ticks with a density of 1.8 ± 0.6 ticks/m². Tick density estimates were not significantly different between the two sampling methods ($t_{52} = 0.8$, $p = 0.9$).

The average height of forbs, grasses, and short shrubs was below 2 m, and the average tall shrub height was above 2 m (Fig. 3.2). Tall shrub height was significantly different among cover types ($F_{5, 195} = 4.7$, $p = 0.003$) with the tallest tall shrub height of 3.2 ± 0.3 m in wet habitats. Tall shrub heights in other cover types were below 2 m tall.

The largest clumps of winter ticks were found at 38.2 ± 3.4 cm although clumps were found at all heights of the chaps (Table 3.1). At sites where more ticks were found on the chaps than on the flag, the most ticks were found from 0 - 66 cm on the chaps and when more ticks were found on the flag than the chaps, more ticks were found from 66-100 cm on the chaps ($\chi^2_2 = 12.9$, $p = 0.002$).

Discussion

Sampled tick densities were similar between flag and walking surveys. Flagging is an effective method for surveying winter ticks in Minnesota if moose locations are known (Chapter 1). The same flagging technique as used in this study collected an average of 16% of seeded ticks in Elk Island Park in Alberta, Canada (Drew and Samuel 1985). The percent of ticks collected with flags increased in thicker forest understories and was less in open bogs and grasslands (Drew and Samuel 1985). Walking surveys are likely to have similar sampling efficiencies, but collect more ticks than flags in open grass and bogs.

Flagging and walking survey techniques were effective at collecting ticks in different vegetation types. In this study, the height of the flag could be changed to sample at ground level or as high as the tops of shrubs 3 m tall. Walking surveys were effective at sampling vegetation less than 1 m tall and the sides of vegetation. Sampling above 1 m

was only possible with the flag, but flag sampling was extremely difficult in thick shrubs that were taller than the reach height of the surveyor. In areas with thick ground shrubs or coarse woody debris, it was easier to move the flag over the tops of the vegetation than to walk the chaps through the brush. In habitats with thickly intertwined or stiff vegetation, flags have also been used to probe to ground level and to the tops of lower vegetation where ticks can occur (Caroll and Schmidtman 1992). Walking surveys were able to sample at ground level without the additional effort.

Ticks were found at a variety of heights during the walking surveys. The preferred height of questing ticks was reported to be 112 cm at the top of vegetation (McPherson et al. 2000). The height of 112 cm is just above the height of the walking survey chaps with the current design, but no clumps of ticks were observed on clothing above the chaps. Actually, few ticks were found above 66 cm in this study. Finding ticks below the preferred questing height suggests that ticks either climbed to lower heights on the vegetation or climbed shorter vegetation in Minnesota.

Ticks are thought to climb to the height of their preferred hosts (50 - 190 cm), but are often limited by vegetation height (1 - 1.5 m, Drew and Samuel 1985, McPherson et al. 2000). Clumps do not always occur on the tallest branch of the tallest vegetation because of the random choice of the climbing vegetation and branches by the ticks and because of guiding pheromones produced by other larval ticks (Drew and Samuel 1985). In Elk Island Park, Alberta, Canada, clumps were found as low as 4 cm off the ground with larger clumps found on the grass (Drew and Samuel 1985). Although tick clumps below 50 cm are not considered biologically relevant (McPherson et al. 2000), winter

ticks occur below that level and should be surveyed to get an accurate index of winter tick abundance.

Ticks lower on the vegetation may have larger impacts on calves. Calf torso height is lower than adult torso height and may cause calves to pick up more ticks from shorter vegetation. Low tick height may have been a factor in calves acquiring 2 times as many ticks as adult moose in Alberta, Canada (Samuel 2004). Because of the metabolic demands placed on calves with large winter tick loads, calves are the most susceptible to adverse effects of winter tick infestations (Musante et al. 2007).

Management Implications

Because tick sampling with flag surveys and walking surveys are similar, surveyors should select the method that matches the vegetation structure the best. Walking surveys with chaps would be appropriate in habitats with varying height of vegetation ≤ 1 m in height, or in dense flexible vegetation. Flag surveys should be used in habitats with vegetation ≥ 1 m with enough spacing to reach the tops of the vegetation. Flags could also be used in habitats with distinctly different vegetation heights.

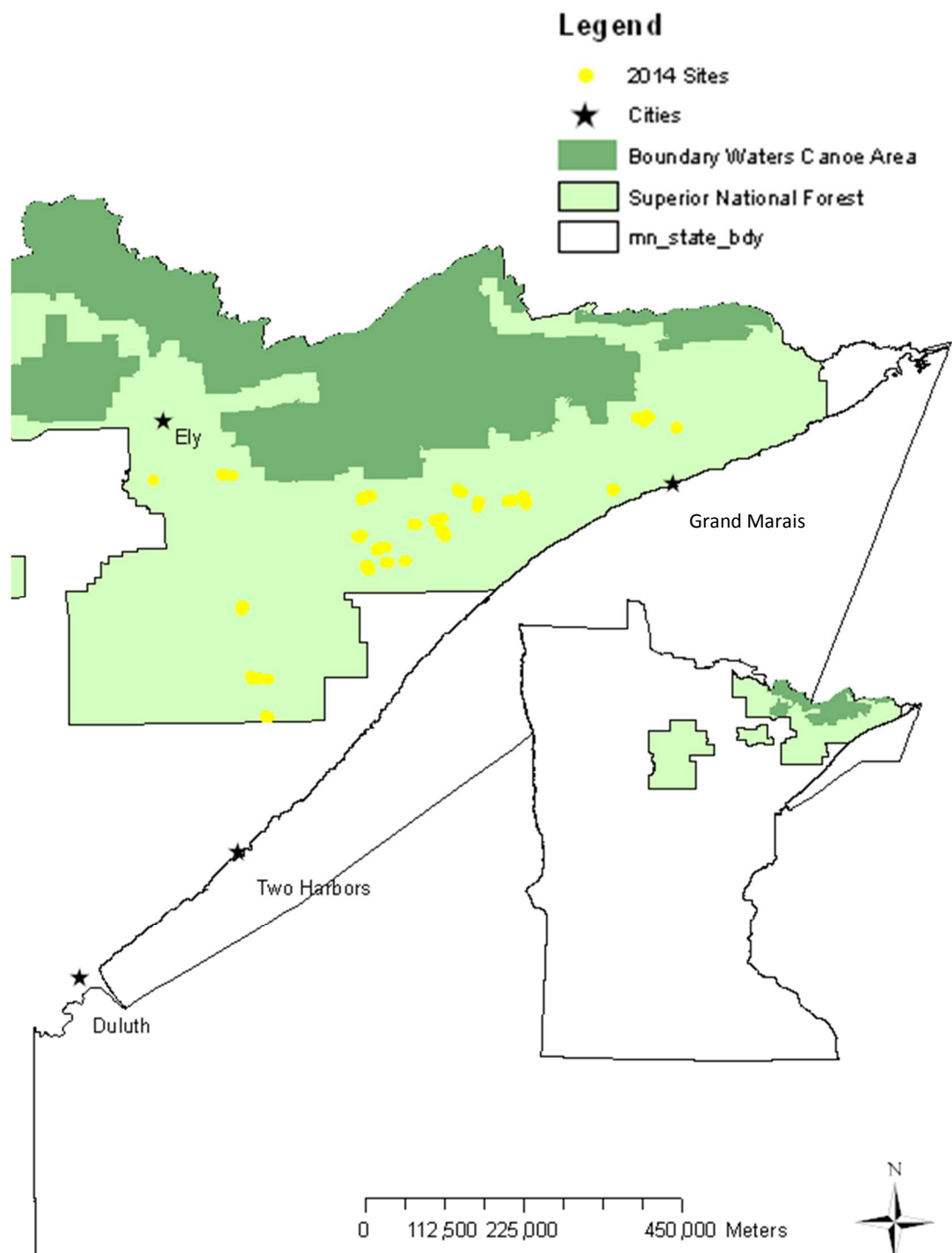


Figure 3.1. Study Area

Table 3.1. Average height and standard error of winter ticks collected on the chaps in the walking surveys.

	Average	SE
Highest Clump (cm)	66.1	3.2
Lowest Clump (cm)	17.1	2.7
Largest / Most Clump(s) (cm)	38.2	3.4
Number of Ticks Lower 1/3	28.0	7.4
Number of Ticks Middle 1/3	41.6	17.7
Number of Ticks Upper 1/3	14.6	5.9

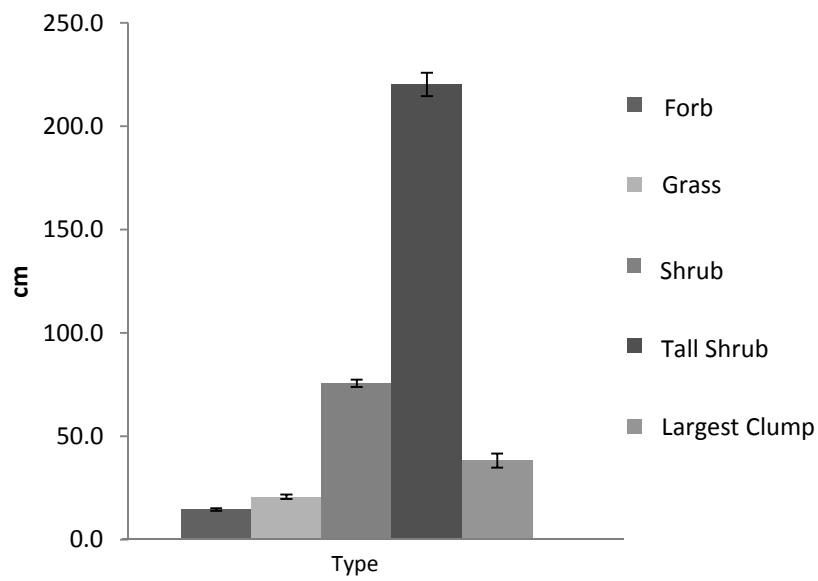


Figure 3.2. The heights of vegetation sampled and the height of the largest clumps of ticks collected.

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